# Characterisation of a PEM electrolyser using the current interrupt method

**Dissertation submitted in fulfilment of the requirements for the degree *Master of Engineering* in Electrical and Electronic Engineering at the Potchefstroom campus of the North-West University**


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# Declaration

I, Christiaan Adolph Martinson hereby declare that the dissertation entitled "Characterisation of a proton exchange membrane electrolyser using the current interrupt method" is my own original work and has not already been submitted to any other university or institution for examination.

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Signed on the 12th day of December 2012 at Potchefstroom.

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# Abstract

The need to characterise a PEM electrolyser is motivated by a South African hydrogen company. One of two electrochemical characterisation methods, namely the current interrupt method or electrochemical impedance spectroscopy, is investigated to characterise the PEM electrolyser. Various literature sources can be found on the electrochemical characterisation methods.

In this study the current interrupt method is used for the electrochemical characterisation of a PEM electrolyser. The current interrupt method is an electrical test method that will be used to obtain an equivalent electric circuit model of the PEM electrolyser. The equivalent electric circuit model relates to various electrochemical characteristics such as the activation losses, the ohmic losses and the concentration losses.

Two variants of the current interrupt method, namely the natural voltage response method and the current switching method, are presented. These methods are used to obtain two different equivalent electric circuit models of the PEM electrolyser. The parameters of the first equivalent electric circuit, namely the Randles cell, will be estimated with the natural voltage response method. The parameters of the second equivalent electric circuit, namely the Randles-Warburg cell, will be estimated with the current switching method.

Simulation models of the equivalent electric circuits are developed and tested. The simulation models are used to verify and validate the natural voltage response method and the current switching method. The parameters of the Randles cell simulation model is accurately calculated with the natural voltage response method. The parameters of the Randles-Warburg cell simulation model is accurately calculated with the current switching method.

The natural voltage response method and the current switching method are also practically implemented. The results is used to indicate the various electrochemical characteristics of the PEM electrolyser. A Nafion 117 type membrane was tested with the current interrupt method. The membrane resistance parameters of Randles cell were estimated with the natural voltage response method. These values are validated with conductivity measurements found in literature. The results of the Randles-Warburg cell is validated with a system identification validation model.

***Keywords:*** *Current interrupt, Current switching, Electrochemical characterisation, Equivalent electric circuit, Natural voltage response, Proton exchange membrane, Pseudo random binary sequence, System identification*

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# List of Acronyms and Abbreviations

| | |
|---|---|
| AC | Alternating current |
| ACF | Autocorrelation Function |
| CI | Current interrupt |
| cRIO | Compact reconfigurable input output |
| CV | Cyclic voltammetry |
| DC | Direct current |
| EEC | Equivalent electric circuit |
| EIS | Electrochemical impedance spectroscopy |
| GDL | Gas diffusion layer |
| HRES | Hybrid renewable energy system |
| LFSR | Linear feedback shift register |
| MEA | Membrane electrode assembly |
| MSE | Mean squared error |
| MLS | Maximum length sequence |
| NI | National instruments |
| NMOSFET | Negative metal oxide semiconductor field effect transistor |
| NVR | Natural voltage response |
| ORP | Oxidation reduction potential |
| ORR | Oxygen Reduction Reaction |
| PEM | Proton exchange membrane |
| PC | Polarisation curve |
| PCB | Printed circuit board |

| | |
|---|---|
| PRBS | Pseudo random binary sequence |
| PSD | Power spectral density |
| RE | Renewable energy |
| SI | System identification |
| SPICE | Simulation program with integrated circuit emphasis |
| WAP | Wireless access point |

# List of Symbols

## Roman letters

| Symbol | Description |
|---|---|
| $c_1$ | Warburg coefficient |
| $c_2$ | Warburg coefficient |
| $f$ | Frequency |
| $f_{clk}$ | PRBS clock frequency |
| $f_{min}$ | Minimum frequency |
| $f_{max}$ | Maximum frequency |
| $f_{me}$ | Maximum excitation frequency |
| $i_0$ | Current density |
| $i_{brr}$ | Backward reaction rate |
| $i_{frr}$ | Forward reaction rate |
| $r_1$ | Warburg coefficient |
| $r_2$ | Warburg coefficient |
| $G$ | Gibbs free energy |
| $C_d$ | Diffusion capacitance |
| $C_{dl}$ | Double layer capacitance |
| $E$ | Electrode potential |
| $E^0$ | Standard thermodynamic potential |
| $F$ | Faraday constant |
| $H$ | Enthalpy |

| | |
|---|---|
| $n$ | number of PRBS stages |
| $N$ | MLS length |
| $R$ | Universal gas constant |
| $R_{ct}$ | Charge transfer resistance |
| $R_d$ | Diffusion resistance |
| $R_m$ | Membrane resistance |
| $T$ | Absolute temperature |
| $T_{clk}$ | PRBS clock period |
| $T_{per}$ | PRBS period |
| $V_{cell}$ | Cell voltage |
| $Z_{wbg}$ | Warburg impedance |

# Greek symbols

| **Symbol** | **Description** |
|---|---|
| $\alpha$ | Charge transfer coefficient |
| $\eta$ | Overpotential |
| $\eta_{act}$ | Activation overpotential |
| $\eta_{ohm}$ | Ohmic overpotential |
| $\eta_{con}$ | Concentration overpotential |
| $\phi$ | Phase shift |
| $\varphi_{xx}$ | PRBS Autocorrelation |
| $\Phi_{xx}$ | PRBS PSD |
| $\Delta_{clk}$ | PRBS clock speed |
| $\tau_{ct}$ | Diffusion time constant |
| $\tau_{rc}$ | RC time constant |
| $\omega_{low}$ | Lower frequency |
| $\omega_{low}$ | Upper frequency |